



# George C. Marshall Space Flight Center ER42 Fluid Dynamics



## Liftoff and Time Equivalent Duration Data Evaluation of Exploration Flight Test 1 Orion Multi-Purpose Crew Vehicle



**5<sup>th</sup> Joint Meeting Acoustic Society of American and Acoustical Society of Japan**  
***Janice Houston***  
November 29, 2016



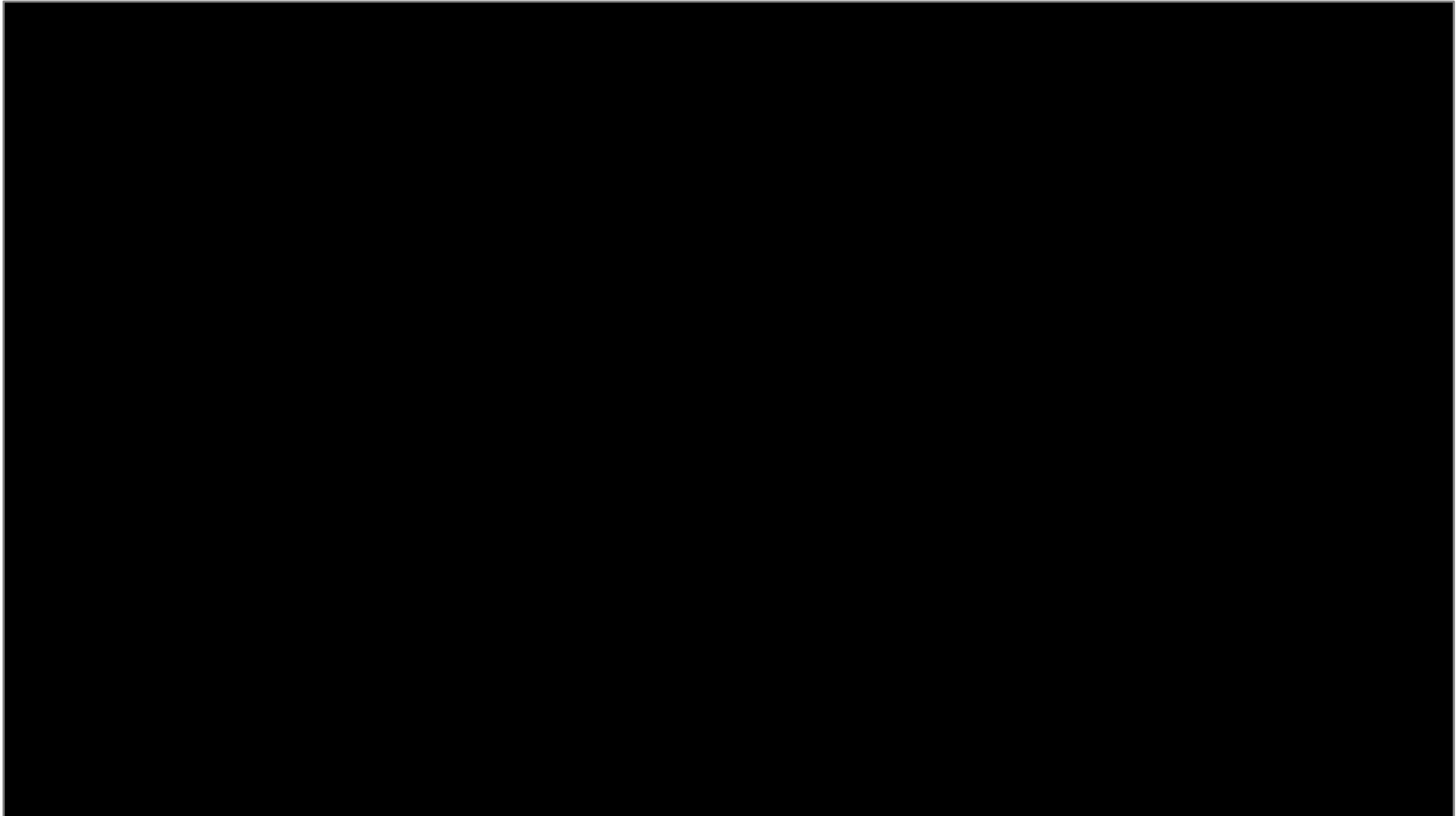
## EFT-1 Mission



# Background



- EFT-1 launch on December 5, 2015 at 7:05 AM EST

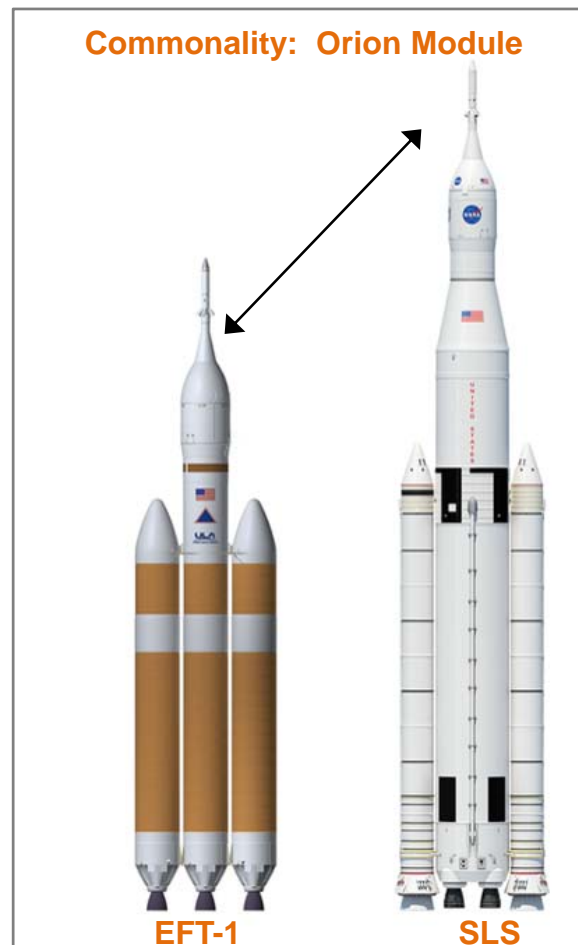




# Objective



- Objective of this work is to define the EFT-1 liftoff acoustics (LOA) fatigue-weighted duration
  - Vibroacoustic engineers require the fatigue-weighted duration for qualification testing
  - Useful for the development of the Space Launch System (SLS)

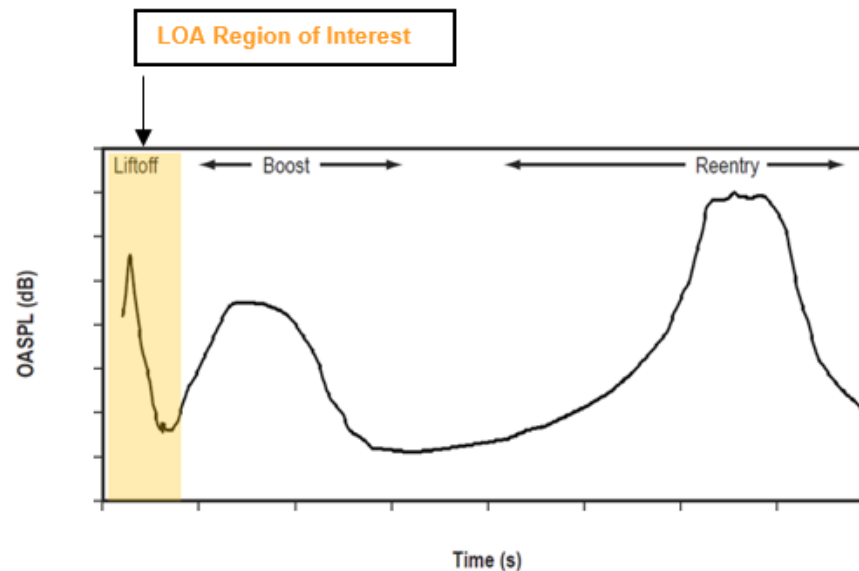




# Objective



- Definition of Fatigue-weighted time duration,  $T_{eq}$ , is taken from:
  - NASA TM-2009-215902: *'Using the Saturn V and Titan III Vibroacoustic Databanks for Random Vibration Criteria Development'*
  - Available at NASA Technical Reports Server <https://ntrs.nasa.gov/>
- From TM-2009-215902:
  - 'Equivalent damage time ( $T_{eq}$ ) is the time required to induce an amount of damage at a high test level equivalent to that induced by exposure to a varying stress level.'
  - Acoustically induced random vibration on launch vehicles is a non-stationary environment, i.e., its root-mean-square (RMS) amplitude changes fairly rapidly over its duration.'





## EFT-1 Instrumentation Overview



# EFT-1

## Vehicle & Instrumentation

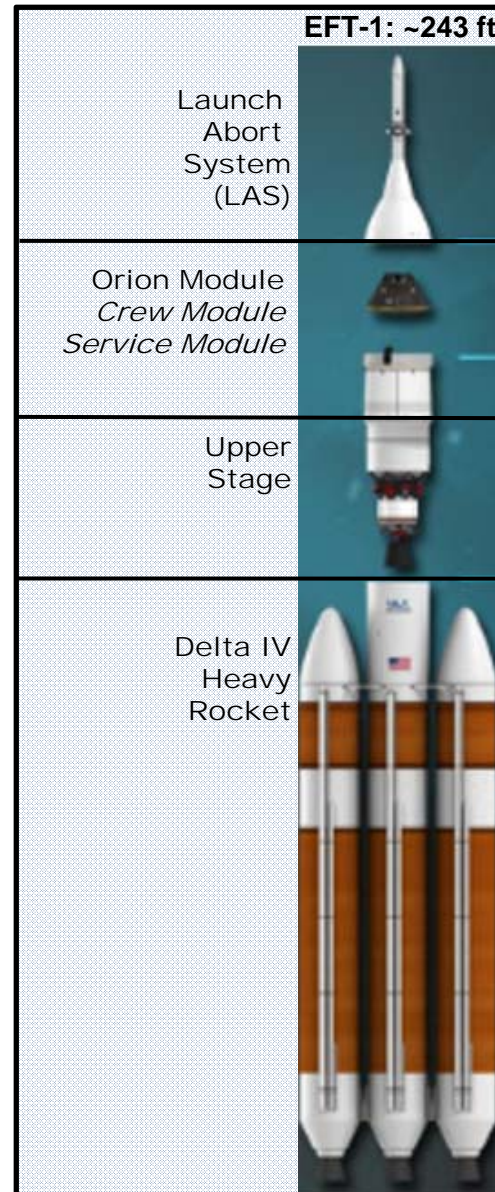


### Sensors: Piezoresistive Pressure Transducers

- External Locations
  - 5 sensors on LAS
  - 17 sensors on Crew Module (CM)/Service Module (SM)
- Internal Location
  - 1 sensor on CM/SM

### Data Acquisition Units

- DAU1: all 5 LAS sensors
- DAU2: 10 CM/SM sensors
- DAU 3: 8 CM/SM sensors



### Sensors

#### LAS

LASM01  
LASM02  
LASM03  
LASM04  
LASM05

#### ORION MODULE

##### OM01int

OM01  
OM02  
OM03  
OM04  
OM05  
OM06  
OM07  
OM08  
OM09  
OM10  
OM11  
OM12  
OM13  
OM14  
OM15  
OM16  
OM17

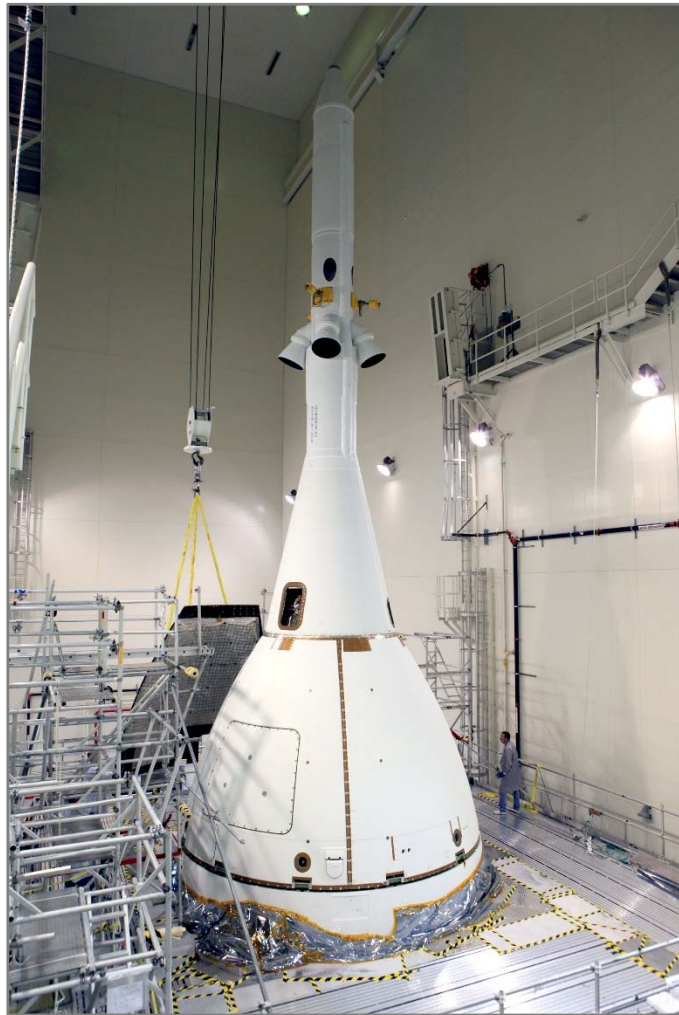
### Data Acquisition Units

DAU1  
DAU2  
DAU3



# EFT-1

## Orion LAS/Ogive and Service Module



Orion LAS/Ogive Cover



Orion Service Module

Photo credit - <http://www.nasa.gov/content/orion-prepares-to-move-to-launch-pad>

Photo credit - <http://www.nasa.gov/content/at-your-service-orion-service-module-complete>



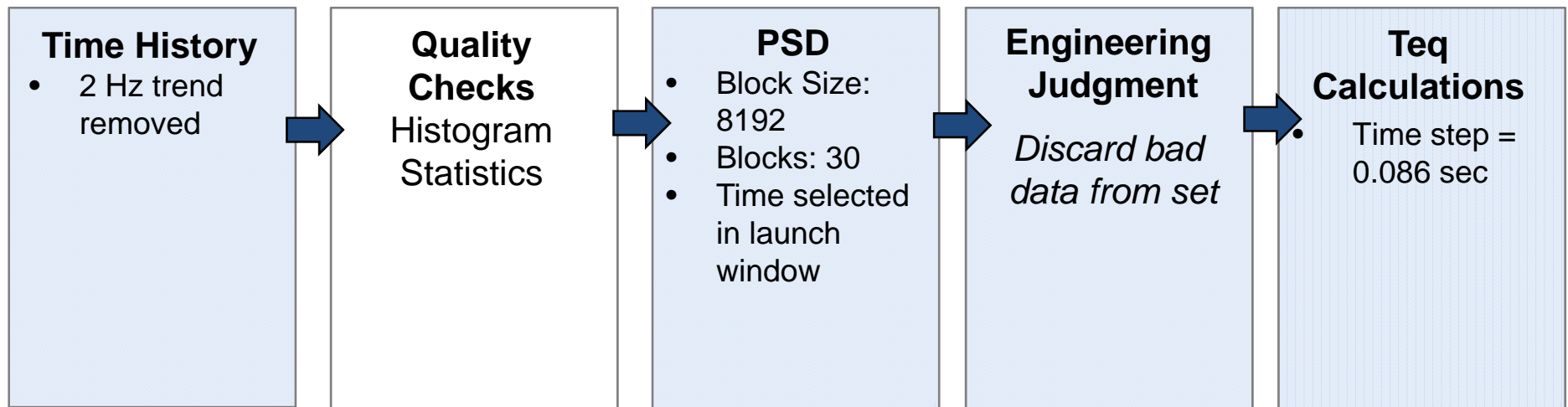
# Data Analysis



# Data Analysis Challenge & Process



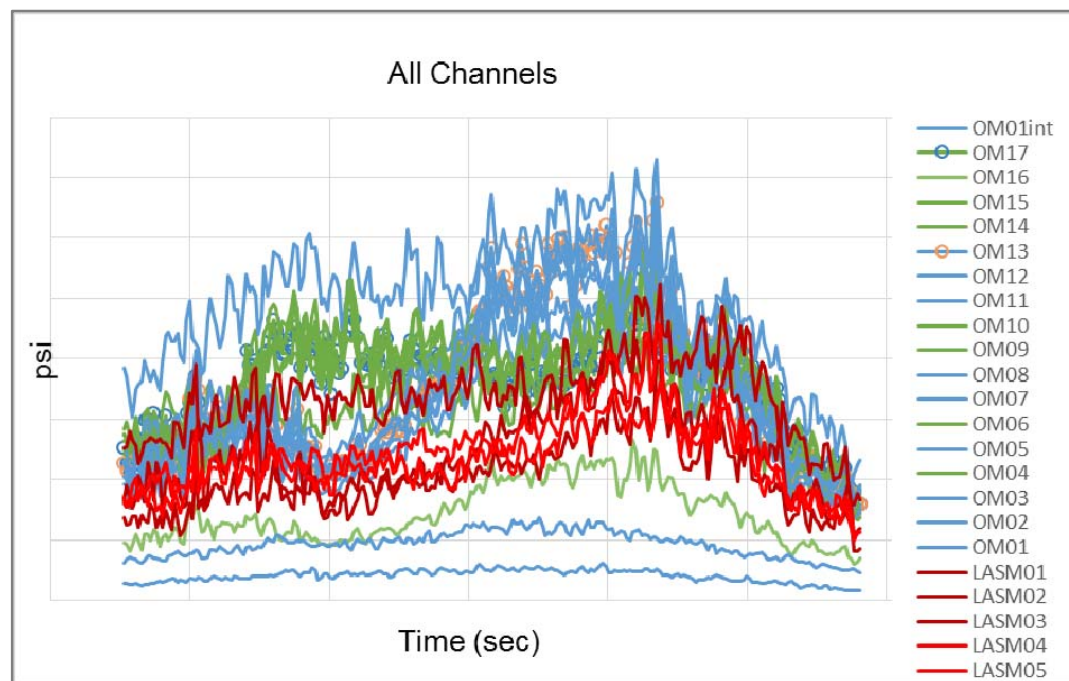
- Challenge: Data “thrown over the fence”
- Analysis Software: PCSignal Version 2.5



\*will discuss blue boxes

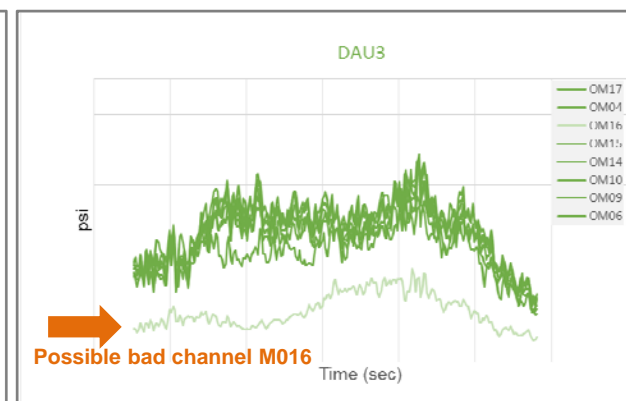
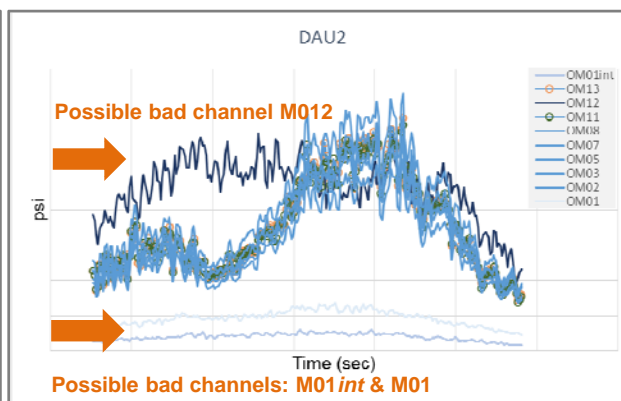
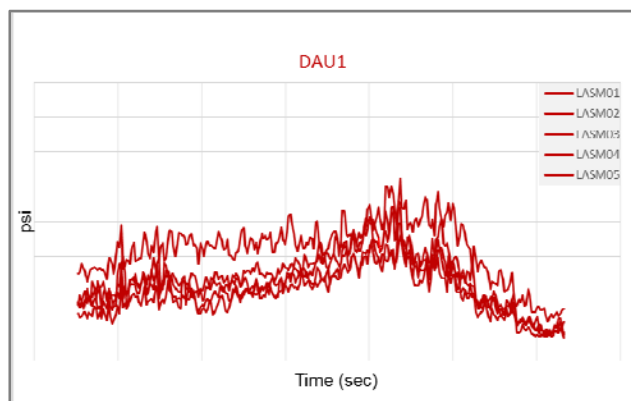


# Time History



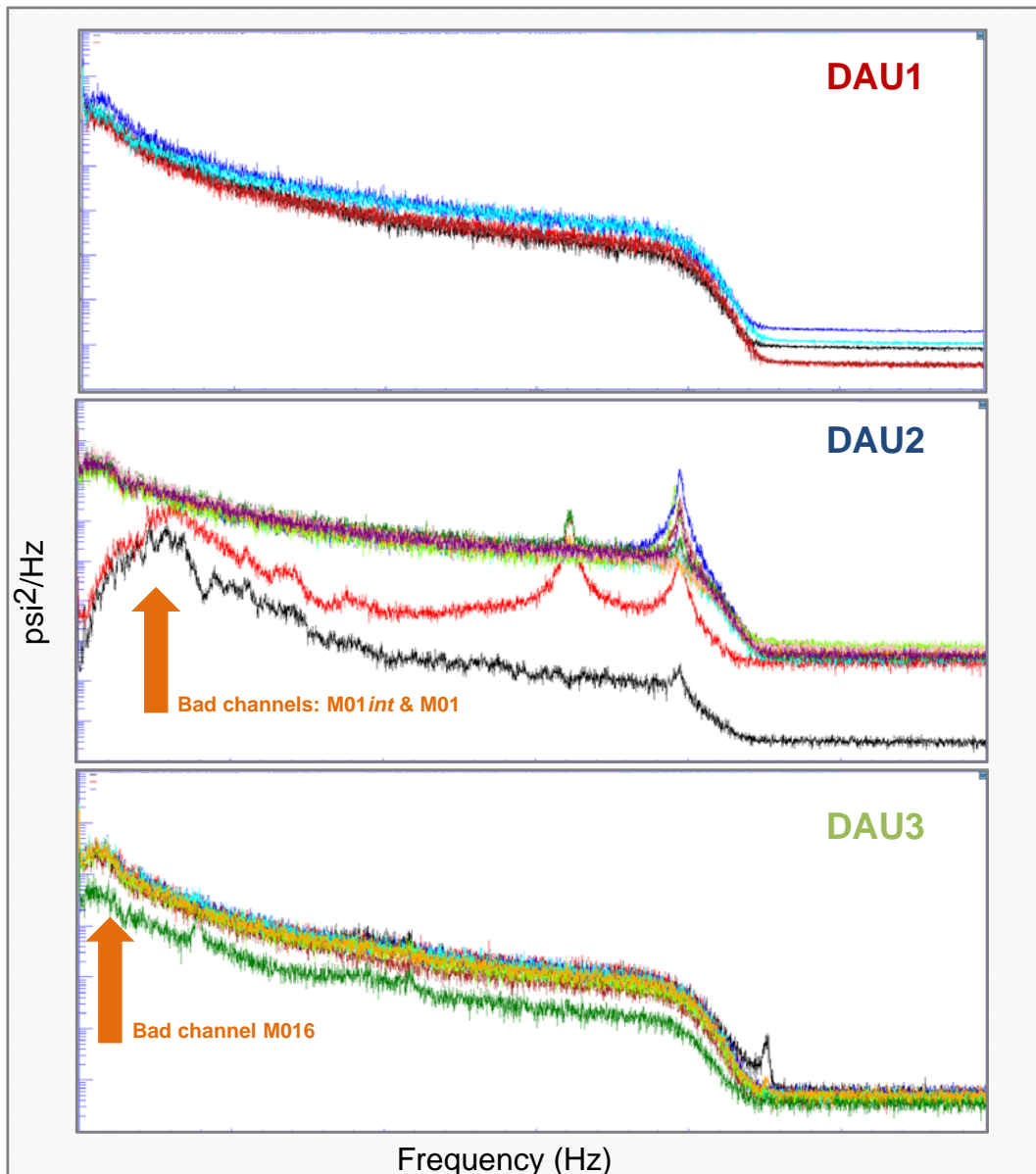
## Evaluation led to:

- Possibility that some channels were “bad”
  - DAU2/M01 *int*
  - DAU2/M01
  - DAU2/M012
  - DAU3/M016 (gain issue)
- Determination that time history shape unique per DAU
- Further data analysis became DAU specific





# PSD Evaluated per DAU



## Evaluation Conclusions:

- **DAU1**
  - Channels look great
  - Filter Rolloff consistent and at expected frequency
- **DAU2**
  - M01int and M01 are not in family
  - Other channels show peak prior to roll-off
- **DAU3**
  - M016 is 10x below other channels in magnitude
- DAUs do not have same characteristics
  - Requires slot evaluation
    - **Two time windows**
    - Ambient
    - Launch window



# Evolved Data Analysis Process



- DAU contains cards which are located and identified by numbered “slots”
- The cards can host multiple channels
  - Cards can host different sensor types simultaneously
- DAU1 – Sensors located on 1 slot
- DAU2 - Sensors located on 4 slots
- DAU3 – Sensors located on 4 slots



Example DAU with Cards (Slots)

| DAU         | Sensor ID with Slot & Channels   |   |  |  |
|-------------|--|---|--|--|
| <b>DAU1</b> | LASM01 – Slot 26 – Channel 1<br>LASM02 – Slot 26 – Channel 2<br>LASM03 – Slot 26 – Channel 3<br>LASM04 – Slot 26 – Channel 4<br>LASM05 – Slot 26 – Channel 5 |   |  |  |
| <b>DAU2</b> | OM11 – Slot 13 – Channel 1<br>OM08 – Slot 13 – Channel 3<br>OM01 – Slot 13 – Channel 5   | OM07 – Slot 14 – Channel 1<br>OM05 – Slot 14 – Channel 3<br>OM01 <sub>int</sub> – Slot 14 – Channel 5 | OM03 – Slot 15 – Channel 1<br>OM02 – Slot 15 – Channel 3 | OM12 – Slot 16 – Channel 1<br>OM13 – Slot 16 – Channel 3 |
| <b>DAU3</b> | OM15 – Slot 13 – Channel 1<br>OM10 – Slot 13 – Channel 3   | OM16 – Slot 14 – Channel 1<br>OM14 – Slot 14 – Channel 3  | OM09 – Slot 15 – Channel 1<br>OM06 – Slot 15 – Channel 3 | OM04 – Slot 16 – Channel 1<br>OM17 – Slot 16 – Channel 3 |

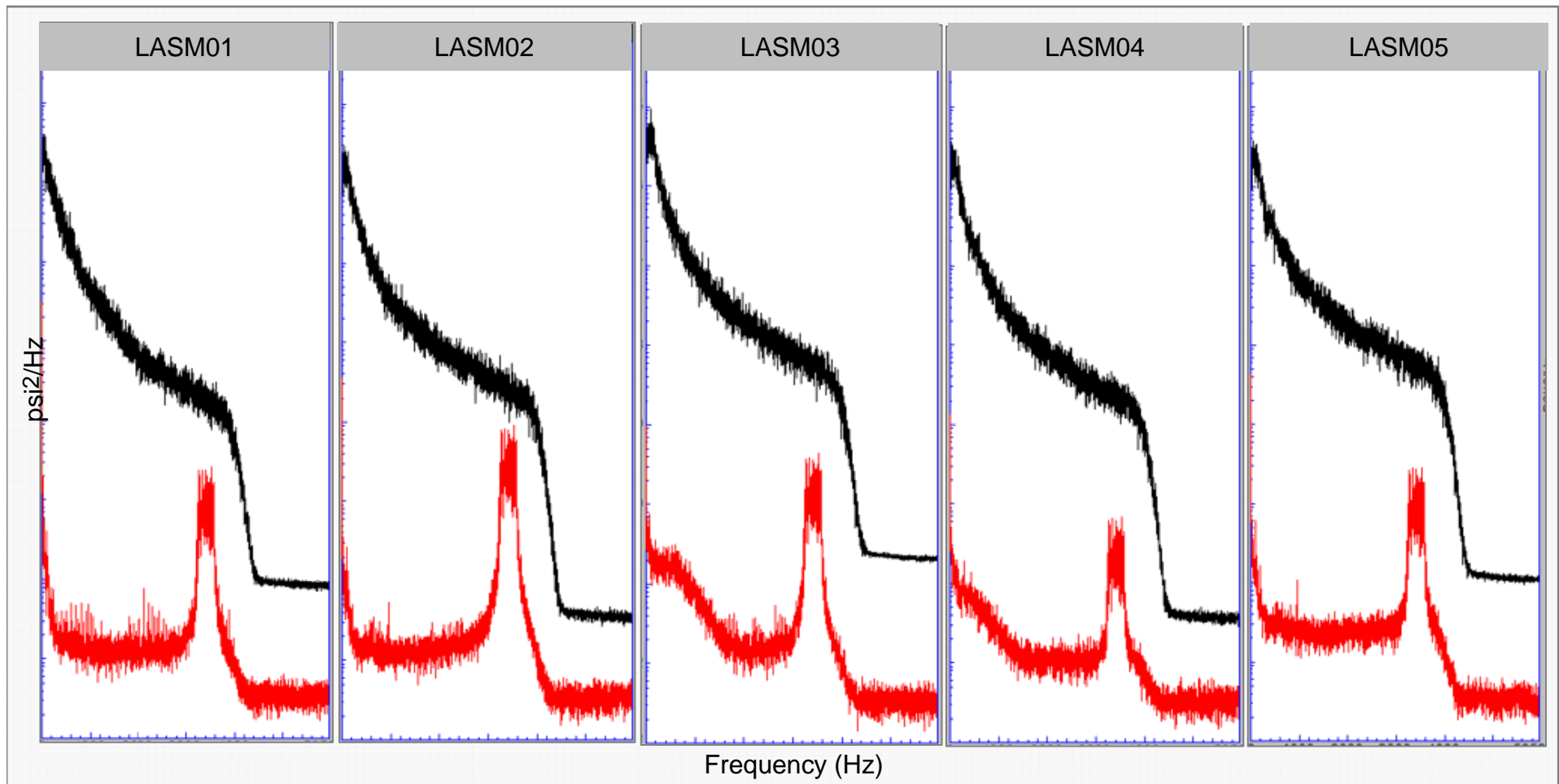


## DAU1 Average PSDs



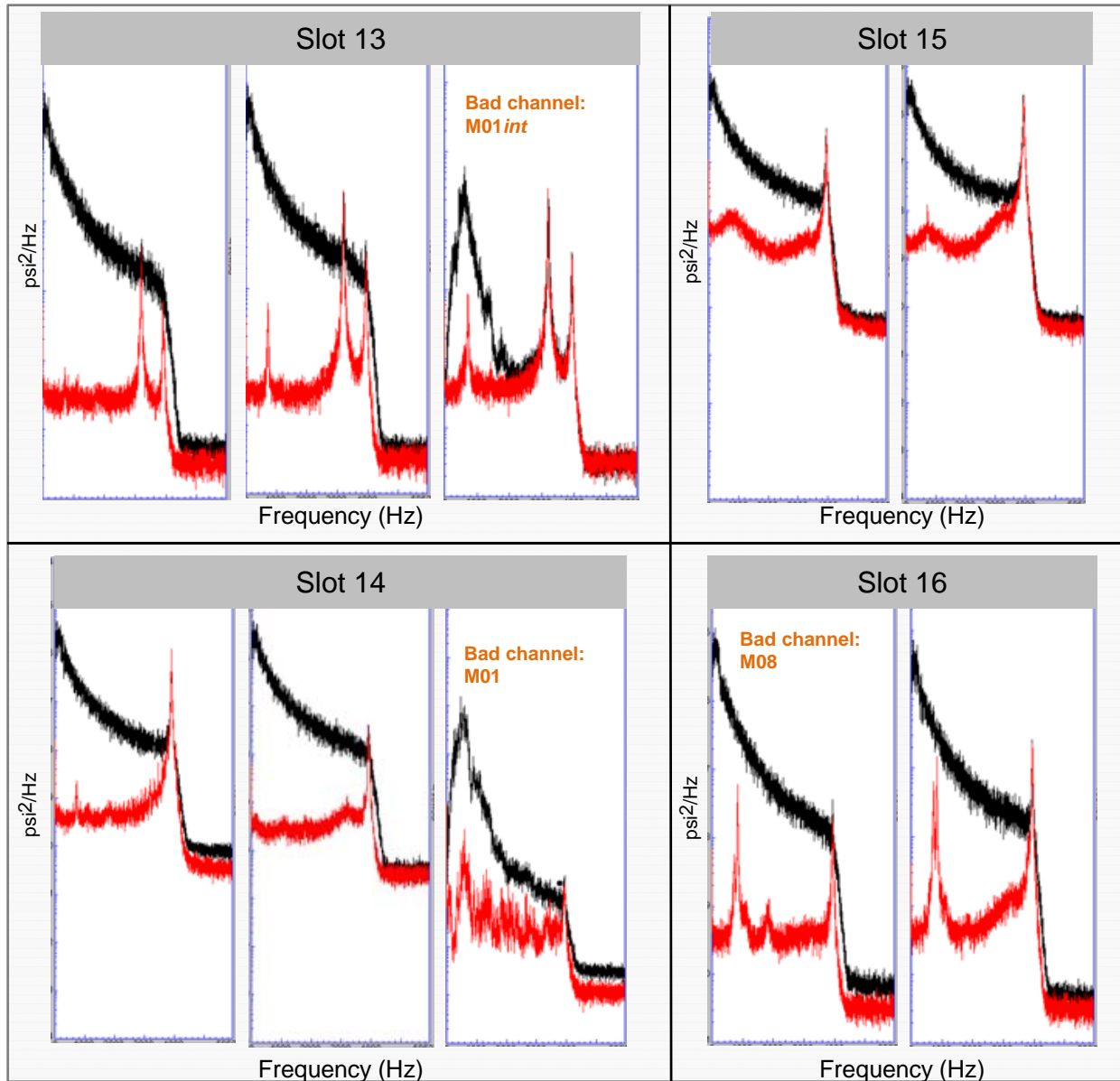
### DAU1 Evaluation Conclusions (1 slot, sequential channels)

- Looks as expected
- Ambient noise window has peak but below signal





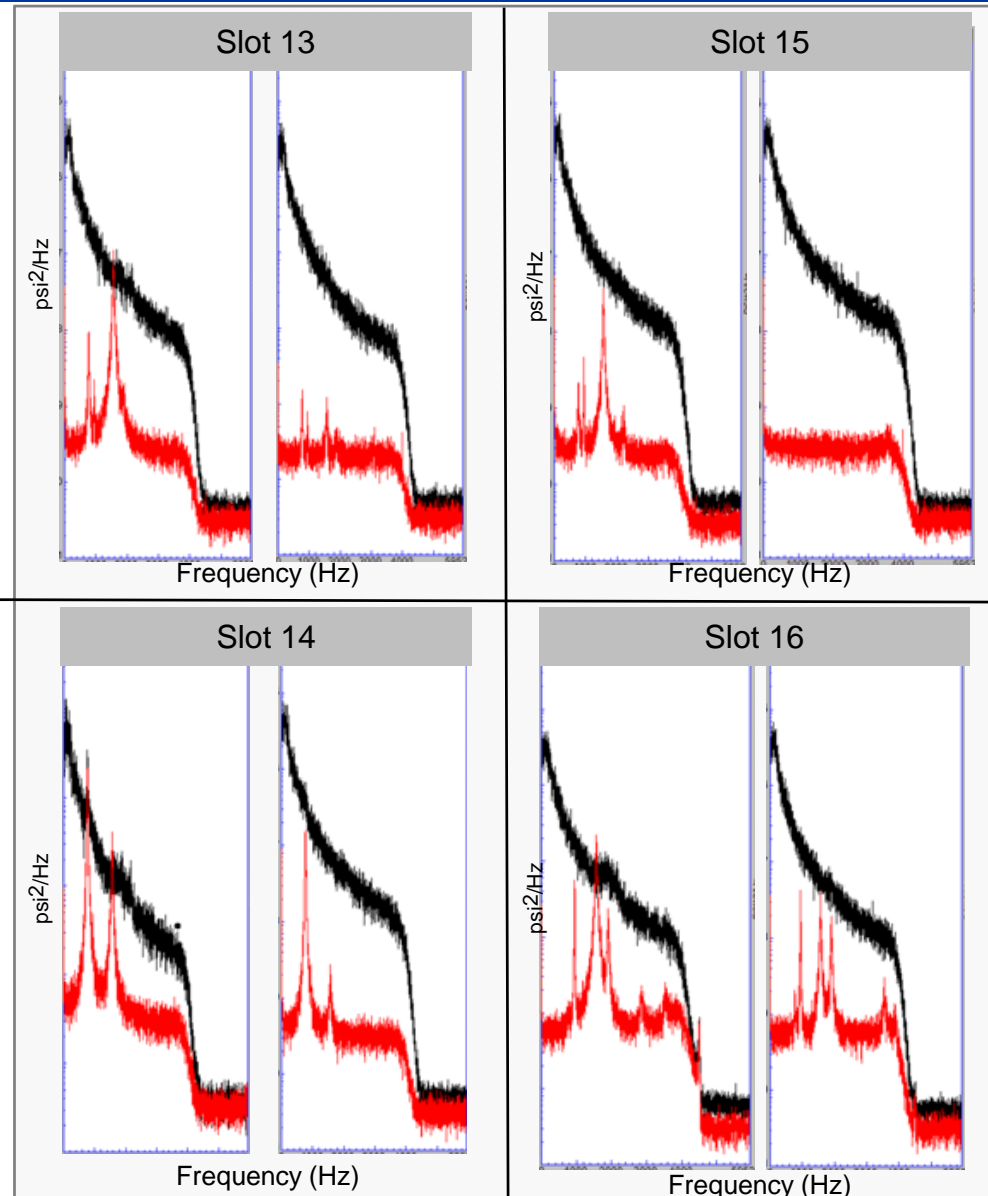
## DAU2 Average PSDs



- **DAU2 Evaluations**  
Conclusions (4 slots)
- Peaks in ambient and liftoff times seem to be slot dependent
- Noise to signal ratio of ambient to launch window peaks insufficient



## DAU3 Average PSDs



- **DAU3** Evaluations Conclusions (4 slots)
- Peaks in ambient and liftoff times seem to be slot dependent
- Noise to signal ratio of ambient to launch window peaks insufficient
- Possible that documentation for channels in Slot 13 and Slot 15 is incorrect



## Teq Calculation and Results



# Definition of Fatigue-Weighted Duration



- Fatigue-Weighted Duration ( $T_{eq}$ ) formula :

$$T_{eq} = \sum_i T_i \left( \frac{W_i(T_i)}{W_{max}} \right)^\beta$$

## For EFT-1T<sub>eq</sub>

- Time step
  - $T_i = 2 * (t_2 - t_1) = 0.086 \text{ sec}$

- where  $\beta = b/n = 4$  for this work (assuming solder joints; conservative)
- Varying RMS level ( $W_i$ ), within a given time step ( $T_i$ ), and max level ( $W_{max}$ )
- For launch vehicle / spacecraft applications, it is preferred to use sinusoidal vibration profiles for  $W$ 
  - Mainly for component vibrations / accelerations
- Sound pressure levels or aero dynamic pressure can be used in place of vibration profiles
  - Assumes that the external pressure environment is linearly driving the component level accelerations*
- Calculation process then needs the  $W$  profile over the flight phase of interest
  - For this work, the liftoff phase of flight is of interest. Liftoff phase (per action) includes:
    - Engine ignition – **not desired for random vibration /  $T_{eq}$  assessment**
    - Full thrust engine – **desired phase of flight**

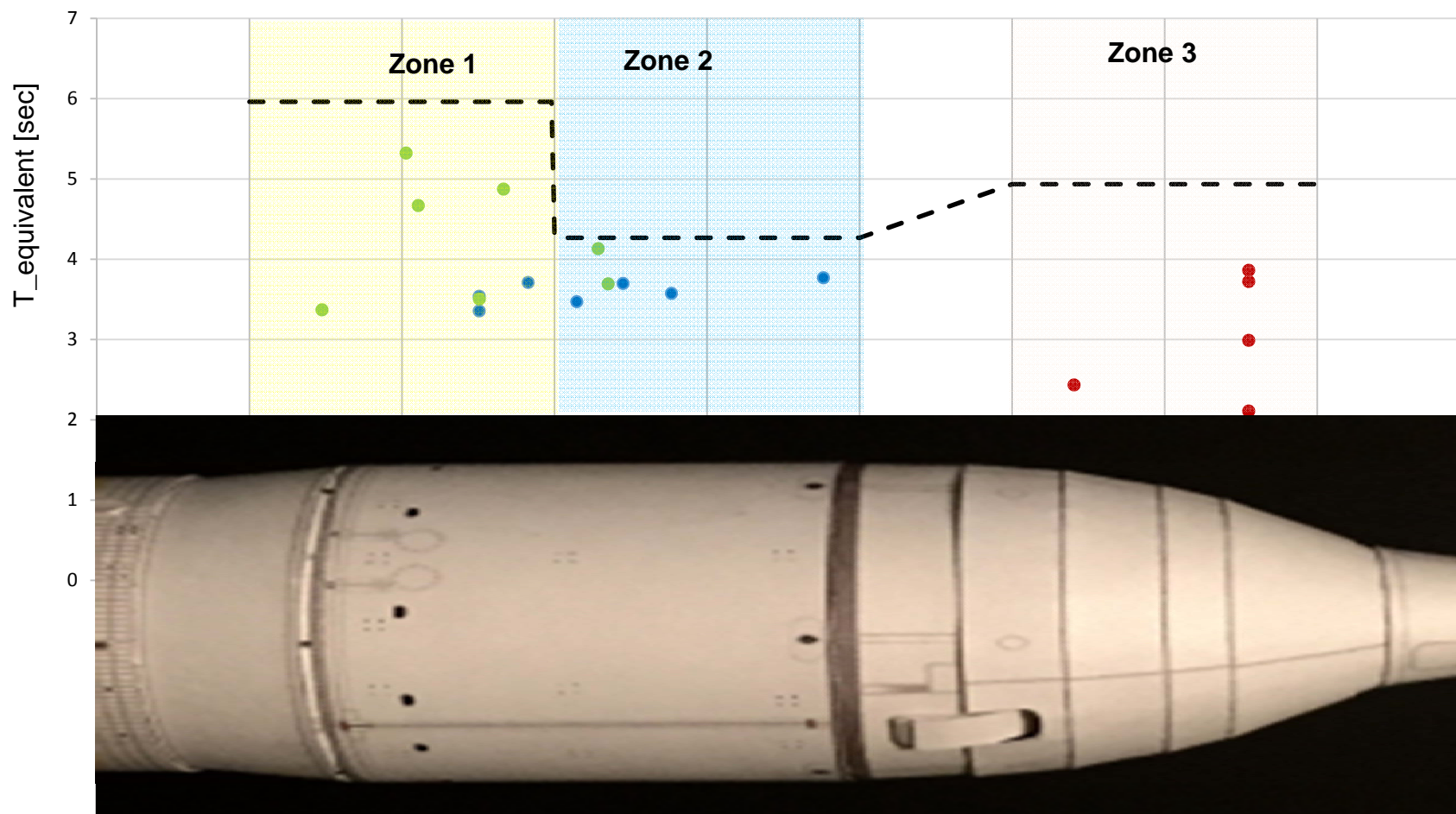


# Teq Results



**Teq trend: longer duration in lower zones, decreasing in upper zones**  
***Consistent finding with other launch vehicles***

- DAU1
- DAU2
- DAU3





# Conclusion



- Data processing has inherent challenges
  - Need good understanding of the data acquisition system in order to avoid false conclusions
- Teq calculations were completed for EFT-1
- EFT-1 launch data can be used for launch vehicles in design
  - Information is useful for SLS



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# **Back up**

## **EFT-1 Mission**



# Delta IV EFT-1 Mission



## DELTA IV EFT-1 MISSION

A United Launch Alliance Delta IV Heavy will take the Orion spacecraft to the highest orbit for a spacecraft designed for humans since Apollo, then deliver it to a re-entry location for splashdown and recovery. Liftoff will occur from Space Launch Complex 37 at Cape Canaveral Air Force Station, FL.

The Orion Exploration Flight Test (EFT)-1 mission is an uncrewed launch of Orion to demonstrate the Service Module (SM) fairing and Launch Abort System (LAS) jettison events, the ability to perform controlled re-entry, and the effectiveness of the heat shield. The Orion spacecraft is built by Lockheed Martin and is comprised of four major elements: the LAS, the Crew Module (CM), the SM, (together, the LAS, CM, and SM comprise the Multi-Purpose Crew Vehicle (MPCV)), and the MPCV Stage Adapter (MSA).

The EFT-1 mission will orbit the Earth twice, reaching a maximum altitude of more than 3,500 miles on the second orbit prior to a starting a steep descent that approaches a lunar mission return thermal environment. The Orion CM will achieve a maximum speed of more than 19,770 mph (29,000 ft/sec) before entering Earth's atmosphere. Following a parachute-aided descent, the Orion spacecraft will be recovered by the U.S. Navy from the Pacific Ocean off the California Baja Peninsula.



Image Courtesy of NASA

### Orion Spacecraft

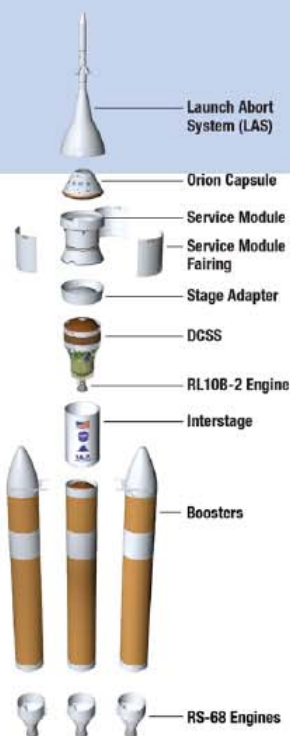
The spacecraft is comprised of the Launch Abort System, the Crew Module, the Service Module and fairings, and the Stage Adapter. The vehicle's height with Orion is approximately 243 ft.

### Delta Cryogenic Second Stage (DCSS)

The DCSS stage propellant tanks are structurally rigid and constructed of isogrid aluminum ring forgings and spun-formed aluminum domes. It is a cryogenic liquid hydrogen/liquid oxygen-fueled vehicle, and uses a single RL10B-2 engine that produces 24,750 lb of thrust. The DCSS cryogenic tanks are insulated with a combination of spray-on and bond-on insulation, and helium-purged insulation blankets. An equipment shelf attached to the aft dome of the DCSS liquid oxygen tank provides the structural mountings for vehicle electronics.

### Boosters

The Delta IV booster tanks are structurally rigid and constructed of isogrid aluminum barrels, spun-formed aluminum domes and machined aluminum tank skirts. Delta IV booster propulsion is provided by the RS-68 engine system which burns cryogenic liquid hydrogen and liquid oxygen which delivers 663,000 lb of thrust at sea level. Booster cryogenic tanks are insulated with a combination of spray-on and bond-on insulation and helium-purged insulation blankets. The boosters are controlled by the DCSS avionics system, which provides guidance, flight control.



The ULA team is proud to be the launch provider for the Lockheed Martin Orion Exploration Flight Test (EFT)-1 mission. The EFT-1 mission represents the next step U.S. crewed space exploration beyond Earth orbit, testing critical interfaces on the Orion and further refining the design that will take astronauts to the moon and beyond.

The ULA team is focused on attaining Perfect Product Delivery for the EFT-1 mission, which includes a relentless focus on mission success (the perfect product) and also excellence and continuous improvement in meeting all of the needs of our customers (the perfect delivery).

My thanks to the entire ULA team and our mission partner, Lockheed Martin, as well as major suppliers of ULA for their hard work and commitment to mission success.

Go Delta, Go EFT-1!

*Jim Spennick*

Jim Spennick  
Vice President, Atlas and Delta Programs



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Join the conversation:



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## MISSION OVERVIEW

- 90<sup>th</sup> ULA Launch
- 8<sup>th</sup> Delta IV Heavy Launch
- 1<sup>st</sup> Commercial Delta IV Heavy Launch





# Delta IV EFT-1 Mission

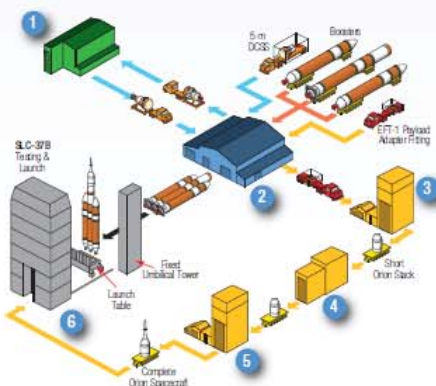


## DELTA IV PRODUCTION AND LAUNCH

- 1 De Soto, CA  
— RS-68 Engine Fabrication at Aerojet Rocketdyne
- 2 Denver, CO  
— ULA Headquarters & Design Center Engineering
- 3 Decatur, AL  
— Boosters, & Second Stage Fabrication
- 4 West Palm Beach, FL  
— RL10 Engine Fabrication at Aerojet Rocketdyne



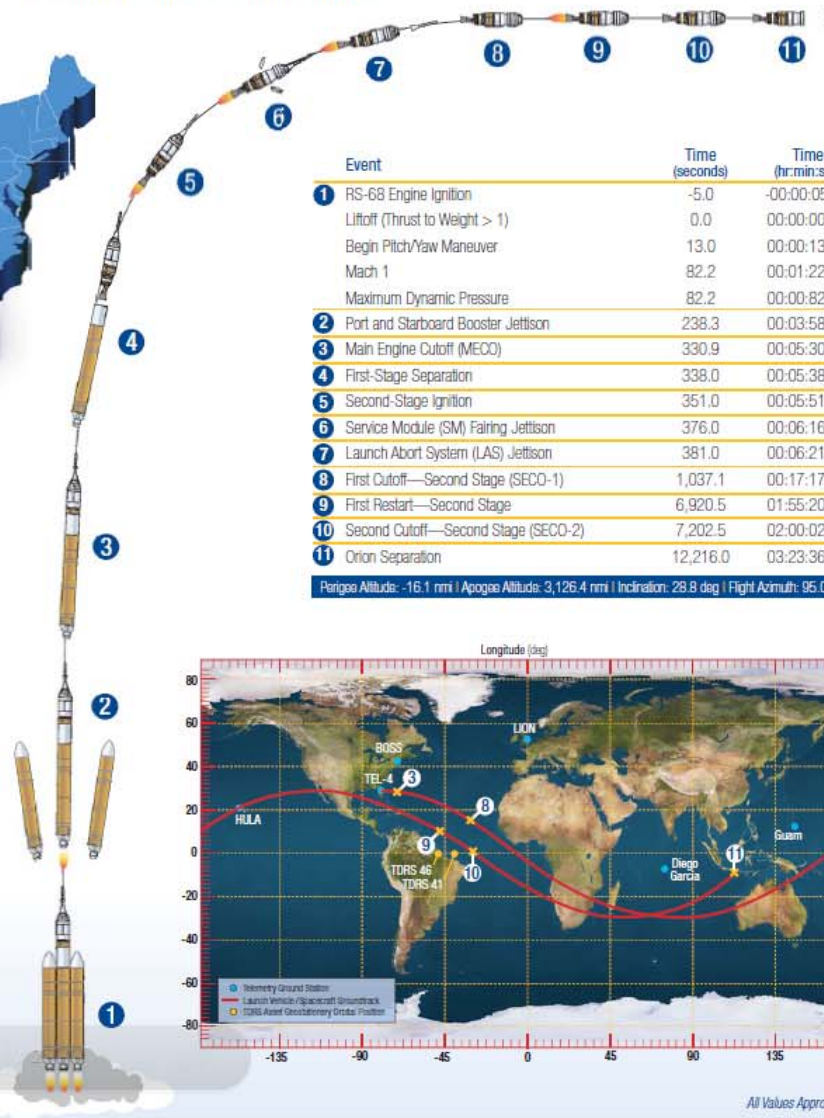
- 1 Delta Operations Center (DOC) | Launch Control Center and Mission Director's Center
- 2 Horizontal Integration Facility | Receiving, inspection and integration
- 3 Neil Armstrong O&C Building | Orion spacecraft assembly and testing
- 4 Payload Hazardous Servicing Facility (PHSF) | Orion spacecraft fueling
- 5 Launch Abort System Facility (LASF) | Launch abort system installation on Orion spacecraft
- 6 Mobile Service Tower | Launch vehicle integration and testing, spacecraft mate and integrated operations



- 1 Mobile Service Tower (MST)
- 2 Launch Vehicle
- 3 Launch Table
- 4 Fixed Umbilical Tower (FUT)
- 5 Lightning Protection Towers
- 6 LH2 Storage Tank
- 7 L02 Storage Tank



## MISSION PROFILE AND GROUND TRACE



All Values Approximate



# Delta IV Heavy and SLS with Orion



## DELTA IV HEAVY

*Orion's Flight Test*

### CAPABILITY TO LOW-EARTH ORBIT (LEO):

*26 metric tons*

### PAYLOAD:

*Basic Orion test structure*

### OBJECTIVE:

*Acquire data at beyond-Earth orbit reentry velocities*

### DISTANCE FROM EARTH:

*3,600 miles*

### DURATION:

*5 Hours*



## SLS

*Exploration Mission One (EM-1)*

### CAPABILITY TO LOW-EARTH ORBIT (LEO):

*70 metric tons*

### PAYLOAD:

*Full Orion*

### OBJECTIVE:

*System readiness for astronauts to travel farther than humans have ever gone before*

### DISTANCE FROM EARTH:

*Will break the distance record reached by the most remote Apollo spacecraft, and then 30,000 miles farther out (275,000 total miles)*

### DURATION:

*22 Days*

